Health & Safety Manual

Supplement 23.01

Work and Design Practices for Electrical Equipment

Approved by the ES&H Working Group

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Work and Design Practices
for Electrical Equipment*

Contents

*** Revised**

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1.0 Introduction

This supplement supersedes the LLNL Electrical Engineering Department Electrical Safety Policy, LED 61-00-01-A1A, and is to be used in conjunction with Chapter 23 of the *Health & Safety Manual*. It contains work and design practices for electrical equipment. The work practices apply to all facility, operational, and programmatic electrical work performed at LLNL. They also apply to employees (managers, designers, users, installers), subcontractors, vendors, and others who are trained, qualified, and authorized to service, maintain, or operate electrical equipment and systems, including research and development (R&D) equipment and systems. Chapter 23 contains a general overview of electrical safety and the various types of electricity that may be encountered at LLNL.

A list of codes, regulations, and standards upon which this supplement is based can be found in Section 6.0.

2.0 Work and Design Practices

Only trained, qualified, and authorized persons are to perform work on LLNL electrical equipment and circuits. These workers shall adhere to the general work practices below in addition to those listed in subsequent sections for specific types of equipment.

- Know the emergency procedures to follow in case of an accident **(dial 911)**.
- De-energize the equipment prior to beginning work, then lock out and tag all hazardous energy sources. (Supplement 26.13 of the *Health & Safety Manual* describes the LLNL Lockout and Tag Program.) Make sure that the controls applied will prevent operation of the equipment and that all hazardous energy, including residual or stored energy, is blocked, discharged, or relieved prior to starting work.

  IMPORTANT: If the equipment must be serviced while energized, apply the work practices in Section 2.1 and those in Table A-1, Appendix A, or prepare a special procedure and have it approved by the appropriate levels of management before beginning the work.
- Never enter alone into an area containing exposed electrical energy sources. Table A-1 provides further details.
- Use appropriate personal protective equipment (PPE). Be sure to check the equipment to verify its effectiveness.

- Use only the test instruments, insulated tools, and PPE rated for the voltage and current specified.

Any deviation from these practices will require Program management to review the operation and prepare an operational safety procedure (OSP).

2.1 Utility, Facility, and Programmatic Power Systems

2.1.1 Utility power systems

Utility power systems include electrical power distribution and transmission systems with more than 600 V (i.e., substations, vaults, transformers, switch gear) that furnish electrical power to buildings and facilities through an electric service entrance. These systems are to be maintained and operated *only* by qualified Plant Engineering personnel (or their designees).

2.1.2 Facility Power Systems

Facility power systems (or building wiring) have less than 600 V and can be found in buildings and facilities downstream of the weather head or service entrance. These systems usually include building lighting, outlets, and installed building equipment (i.e., heating, ventilating, and air conditioning (HVAC) systems) and are to be maintained and operated *only* by qualified Plant Engineering personnel (or their designees).

2.1.3 Programmatic Power Systems

Programmatic power systems may include electrical power distribution and transmission systems with more than 600 V (i.e., substations, vaults, transformers, switch gear) and low-voltage systems (<600 V) that supply power to programmatic equipment. These systems are to be covered by an OSP or facility safety procedure (FSP) and maintained and operated by programmatic personnel (or their designees). Identification and labeling requirements for these systems' electrical panels and associated equipment can be found in the Plant Engineering Panel Board and Circuit Numbering Standard, PEL-E-16196.

Work Practices. **(The work practices listed below apply to utility, facility, and programmatic power systems.)** It is the policy of LLNL in general, as well as the Electronics Engineering Department, Plant Engineering Electric Utilities Division, and the Electric Main Shop in particular, to work on electrical circuits and equipment while de-energize (described in Supplement 26.13). However, if it is safer or essential to perform work on equipment while energized, the precautions below and those in Appendix A are to be taken to minimize electrical hazards. Note that programmatic convenience is not sufficient cause to work on energized equipment.

- Work that is not in compliance with the guidelines in Appendix A requires an OSP. Work covered in the Plant Engineering *High Voltage Distribution System Operations Manual* is exempt from this requirement.
- The PPE specified in the OSP, FSP, or other work guidance documents shall be worn. The appropriate supervisor or facility manager shall ensure that this

equipment is inspected and tested before use. Specialized PPE (insulating gloves, hoods, hose, blankets, and sleeves) is also available from your supervisor, the Electric Utilities Division, or the Electric Main Shop.

- Personal protective equipment must be protected from damage during storage and use. Any damaged equipment must be removed from service immediately and repaired or replaced. Additional information on PPE can be found in Chapter 10 of the *Health & Safety Manual*.
- Warning signs and barriers must be installed when any worker may be exposed to hazards associated with electrical work. Enclosures (cabinets, panels, components, etc.) containing high-voltage equipment (>600 V) shall be labeled with the highest voltage to which a worker can be exposed in the event the panel is opened. Furthermore, enclosures with electrical sources that could expose unqualified personnel to live parts shall be locked or secured with a mechanism (e.g., bolts) that requires a tool to open it.
- Work on energized panel boards shall be conducted only when it is essential to do so. Molded-case circuit breakers opposite each other in the same panel shall not be removed at the same time if the panel board is energized. Installation hardware shall be checked for manufacturer-recommended torque requirements.

2.2 Research and Development Systems

NOTE: Equipment covered in this section is found predominantly in R&D systems at LLNL; however, some of this equipment is also found in other systems operated and maintained by Plant Engineering. Therefore, the work and design practices specified in this supplement also apply to systems maintained by Plant Engineering.

Research and Development (R&D) systems include racked research equipment, power supplies, capacitor storage banks, laser equipment, computer equipment, instrumentation systems, and control systems or, in general, any system that is purchased or fabricated for use by one or more of the Laboratory’s research programs. The Engineering Directorate provides specifications for these systems as well as design, fabrication, installation, operational, and maintenance support.

There is a broad range of hazards associated with R&D systems. Many of these hazards are different from those found in facility or utility systems. This makes it difficult to establish a single set of electrical safety requirements that can be applied uniformly; therefore, general electrical safety guidelines also shall be applied to R&D systems throughout the Laboratory. Further, it is important for personnel working on or around these systems to be trained and qualified and to follow the policies set forth in this supplement and Chapter 23 of the *Health & Safety Manual*.

Research and development equipment should be examined for electrical safety as extensively as possible. Areas to be considered during this inspection include, but are not limited to the following:

- Failure modes.
- Heat effects.
- Magnetic effects.
- Grounding and bonding requirements.
- Guarding of exposed live parts.
- Leakage currents.
- Dielectric testing.
- Access to serviceable parts.
- Over-current and over-temperature protection.
- Clearances and work space.
- Design and procedural documentation.
- Signs, labels, and administrative controls.
- Stored energy.

This inspection shall be documented to include the tests performed, conditions of acceptability, standards used for equipment evaluation, and any limitations of approved usage.

2.2.1 Power supplies

Power supplies that can deliver energy in excess of 10 J at more than 50 V are considered potentially hazardous, and the hazards shall be identified. Electrical hazards in areas or equipment accessible to unqualified personnel shall be identified by an appropriate warning sign. Internal component failure of power supplies can result in excessive voltages across components that may not be appropriately sized. An internal component short in a capacitor bank may result in excessive fault current, extremely high temperatures, over-pressurization of components, fires, and explosions. Overloading or improper cooling of power supplies can cause excessive temperatures and fires. Output circuits and components may remain energized after input power is secured. Power supplies serving more than one experiment may create additional hazards for operators unfamiliar with the equipment. Therefore, potentially hazardous power supplies shall have an integral or automatic system to discharge the output to ground when the input power is turned off, lights to warn personnel that the power supplies are energized, and a positive means of disconnecting the power input. A power supply need not have a lockout device if it is powered by a cord and plug, provided that the plug is under the positive control of the worker.

Low-voltage, high-current power supplies. R&D systems may include equipment that operates at less than 50 V. Although this voltage level generally is not regarded as hazardous, high-current levels generated by these systems may be hazardous. Furthermore, inadvertent grounding of conductors may result in arc flashes and burns, and inductive circuits may create high-voltage hazards when interrupted. For these reasons, low-voltage, high-current systems should have adequate protective covers or barriers, appropriate warning labels, and components suitable for the intended use. Magnetic fields should be evaluated where high-current equipment is used. CAUTION: Magnetic fields may pose a hazard to personnel with implants such as pacemakers.

High-voltage, low-current power supplies. Power supplies with output currents less than 5 mA pose virtually no electrical shock hazard. In hazardous locations (described in Section 2.3), however, such equipment may spark and cause an explosion. Voltage surges in excess of normal ratings may result from faults or lightning. Overcurrent protective devices (fuses or circuit breakers) for conventional applications may not be adequate for highly inductive direct-current systems. Stored energy in long cable runs may cause additional hazards. Thus, all energized parts should be guarded or shielded or an analysis of the associated hazards shall be conducted by the program supervisor, along with other qualified persons from the program and members of the cognizant ES&H Team, prior to starting work.

2.2.2 Batteries and Battery Systems

Design Practices

- Batteries and battery systems present certain risks to workers, including electric shock. Storage batteries in particular can cause burns, due to the high current potential present in battery systems and from electrolyte (acid) within the cells. Batteries being charged may produce a flammable gas (hydrogen) that may explode in the presence of an ignition source (i.e., sparks or flames). Therefore, battery systems shall be designed, installed, maintained, and tested in accordance with the requirements in IEEE Standards 450 and 484, 29 CFR 1926, and NFPA 70. Battery systems used for emergency and standby power (uninterruptible power systems (UPS)) shall be designed, installed, tested, and maintained in accordance with the requirements in NFPA 70 and NFPA 110A.
- A disconnecting means (or switch) is required where more than one direct-current, cell-line-process power supply serves the same cell line. This switch shall be installed on the cell-line circuit side of each power supply so that it can be easily disconnected from the cell-line circuit should this become necessary.

Work Practices. The guidelines below apply when work is performed on or around batteries or battery systems. *These guidelines do not apply to small appliances that contain small batteries.*

- Locked enclosures, accessible only to qualified personnel, shall be provided for all battery system installations. Safety guidelines for specific battery systems shall be obtained and followed.

- Warning signs shall be posted specifying the PPE (i.e., aprons, goggles, and rubber gloves) required to service batteries. In the event that an acid exposure is possible, an emergency eyewash or shower shall be available within 100 ft or a 10-second travel time from the battery system.
- To avoid the potential of an explosion, no sources of ignition (i.e., sparks or flames) shall be present nearby when charging batteries. In addition, battery areas should have adequate ventilation.
- All exposed live parts shall be guarded or insulated to prevent tools or other objects that have been dropped from shorting between polarities or terminals. The use of insulated tools is recommended for work on battery systems. Guidelines for working on energized circuits can be found in Table A-1 of Appendix A.

Chapter 6 of the *Health & Safety Manual* provides further information on battery systems, including requirements for battery-charging areas.

2.2.3 Capacitors

Capacitors specified or purchased shall be in full compliance with the requirements in the current version of ANSI/IEEE Standard 18 (Shunt Power Capacitors). In addition, the following design and safe work practices must be in place:

Design Practices

- Until they are discharged and grounded, hazardous capacitor banks or enclosures shall have interlocks to prevent unauthorized personnel from gaining access.
- Capacitors with stored energy greater than 10 J shall have voltage indicators so that personnel can check the status before accessing the electrical enclosure. A “hot stick” voltmeter may be used to obtain measurements. Provisions shall be made to verify whether the voltage indicators are working both before and after the capacitors are tested. If the capacitor or capacitor bank requires an OSP, it shall include procedures for using and testing voltage indicators.
- Manual grounding devices shall be installed with capacitors and used, even if automatic discharge systems are used.
- Capacitors shall be physically grounded regardless of the existence of bleeder resistors, dump switches, interlocks, or other potential de-energizing devices. Grounding devices shall be placed at low-impedance points and kept in these positions while personnel are in the enclosure. All terminals shall be grounded to ensure full discharge. CAUTION: Grounding of a hot terminal while the nominal grounding terminal is floating will not ensure personnel safety.
- Discharging and grounding systems shall be designed so that personnel will not be exposed to flying molten metal from high-current electric arcs.

- Bleeder resistors shall be included in the design of all capacitor banks in accordance with the requirements in ANSI/IEEE Standard 18. Section 7.12 of this standard specifies that the time for decay of residual voltage to 50 V or less shall not exceed 5 minutes for capacitors rated higher than 600 V or 1 minute for capacitors rated at 600 V or less.
- A faulty capacitor in a capacitor bank may rupture, sometimes explosively. Depending on the type of dielectric used, the rupture could lead to a fire or release toxic gases. To control such hazards, special fire-suppression and ventilation systems shall be provided when designing a capacitor bank enclosure. Procedures for safely handling capacitors containing the dielectric material polychlorinated biphenyl (PCB) oil can be found in *Guidelines for Polychlorinated Biphenyls* (UCRL-AR-111754), which is an appendix to the *Environmental Compliance Manual*. When fault currents cannot be limited by fuses, the design shall include a barrier or enclosure around the capacitor bank to protect personnel from any projectiles.
- High-energy density capacitors are manufactured using new technology that involves series or parallel matrix of elemental capacitors. A common problem with these capacitors is that one or more of the elemental capacitors can become open-circuited while being charged. Thus, provisions shall be made to measure the capacitance of these capacitors and to identify those that have partially failed. Another complicating issue is that the aging effect for these capacitors contributes to a gradual decrease in their capacitance value due to the repeated action of “self-healing” dielectric.

  NOTE. Charged capacitors can fail if an internal circuit to one of the terminals is opened. Be sure to short the terminals to the case when handling faulty capacitors. Also size the shorting element to handle the maximum short-circuit current from a fully charged capacitor. Jarring or temperature changes could connect the internal open connection.
- Because a disconnected and discharged capacitor can self-charge (due to dielectric memory effects) or accumulate a charge by being placed in an electric field, all capacitors shall be short-circuited with a drain wire and grounded, if appropriate, to the case when not in use.

Work Practices

- Capacitors shall be isolated with barriers or enclosures to prevent contact with charged terminals.
- Personnel shall wear eye protection when applying manual grounding devices to all capacitors and hearing protection when the stored energy is more than 10 kJ.

2.2.4 Cathode-Ray Tubes

Work Practices. The following precautions are to be taken when handling cathode-ray tubes (CRTs):

- Don eye protection and gloves.
- Short and ground the terminals to the outer coating.
- Carefully store and transport CRTs to prevent breakage. Use the original shipping boxes, if available.

2.2.5 High-Voltage Equipment

Work Practices. Electrical equipment operated over 10 kV in a vacuum may produce x rays that can penetrate the vacuum enclosure. Furthermore, equipment that does not normally emit x rays can do so through an inadvertently heated surface, by addition of a sharp point or edge to a surface, by a change in the location of a part, or by a change in material or surface treatment. Similarly, a minor change in the vacuum pumping operation may produce a hazardous situation. Therefore, particular care shall be exercised even during slight modification of high-voltage equipment.

Chapter 33 of the *Health & Safety Manual* provides additional information on x rays.

2.2.6 Electrical Interlocks

Design Practices. Electrical interlocks are safety devices usually designed to de-energize electrical circuits when personnel access an electrical hazard area. Panels, doors, and other entryways that permit access to enclosures surrounding electrical hazards are to be bolted, locked, and interlocked. Interlock circuits intended for personnel protection must be designed such that the process of bypassing or completing the interlock chain will not automatically start the equipment.

Work Practices. Interlock circuits must be checked for proper operation after each installation or modification and annually thereafter. Conditions found during inspection shall be noted in the equipment log or other record.

If a lock-controlled master switch is used in the interlock chain, the same key that controls the lock shall be used to gain access to the equipment. A status panel shall be used to continually monitor interlock circuits that de-energize exposed terminals that operate at 50 V and greater, and to automatically discharge the stored energy of capacitors that operate at more than 10 J at levels greater than 50 V. Additional information can be found in Section 2.2.3, “Capacitors.”

More specific information on the design, installation, and testing of personnel safety interlock systems can be found in Supplement 11.07 (Personnel Safety Interlocks) of the *Health & Safety Manual*. Information specific to laser systems and radiation-generating devices can be found in Chapter 28 and Supplement 33.47 of the Manual, respectively. Additional requirements for maintenance and inspection can be found in the current version of NFPA 70B, “Inspection Frequency.”

2.2.7 Machine Tools

Work Practices. Machine tools are defined as electrical or electronic equipment, apparatus, or systems supplied as part of non-portable industrial machinery operating at less than 600 V. The following work practices apply to machine tools:

- Only trained and qualified personnel in the Machine Tool Services (MTS) group of the Manufacturing and Materials Division (MMED) (or other designated LLNL employees or outside vendors) are authorized to service, maintain, repair, and install modifications on electrical equipment or systems used with or in machine tools. These activities shall be carried out in compliance with the requirements in the current versions of NFPA 70, NFPA 79, ANSI/UL 1624, and 29 CFR 1910.
- The MTS Group shall inspect, certify, and approve all LLNL machine tools prior to use. Certification (a work order on file that documents the inspection conducted by MTS personnel) is required for newly installed machine tools, existing machine tools that have been relocated, and any machine tool that has been repaired or modified.
- The Equipment Acquisition Section of the MTS group shall prepare specifications and acceptance test requirements for acquiring new machine tools. These specifications shall comply with all applicable electrical safety standards and requirements. If unusual safety requirements or significant electrical risks are involved, these shall be coordinated by MTS personnel with the Safety Officer for the Engineering Directorate and the Technical Support and Policy Development (TSPD) Division of Hazards Control. Acceptance tests may be conducted by any qualified person designated by the program management purchasing the new equipment.

2.2.8 Power Disconnect Equipment

Design Practices. The following practices apply when designing or specifying disconnect switches and circuit breakers:

- Power disconnect switches and circuit breakers shall have a lockout device designed to minimize the probability of accidental removal, to prevent access by unqualified personnel, and to support a force of no less than 50 lb. These devices also shall be capable of being locked with a padlock in the open (off) position. This padlock functions as a positive disconnect point when applying the lockout and tag procedure in Supplement 26.13 of the *Health & Safety Manual*.
- Circuit breakers shall be identified by their circuit number and the function to be disconnected.
- Power disconnect switches shall be installed with their handles in the down (or off) position.

Work Practices. Power disconnect equipment may be secured with a lock of suitable size for administrative or operational purposes. A yellow caution tag

(Form LLNL-CNOC-30575-SLT, stock number 4280-71958) shall be attached to the equipment; a danger sticker is not required.

2.2.9 Equipment Enclosures

Design Practices. Enclosures shall be designed in full compliance with applicable codes, regulations, orders, and standards for their intended application and for use in the worst-case environment. In addition, the following design practices apply:

- As specified in the current version of ANSI / NEMA 250, enclosures shall be installed around electrical equipment as an adequate guard (or barrier) to prevent injury or death.
- Enclosures shall be designed with adequate ventilation as specified in ANSI / NEMA 250. The openings for non-ventilated enclosures shall not be larger than those specified in Section 6, Subpart 6.2.1.1, of ANSI / NEMA 250.
- The spacing around an enclosure shall be adequate to permit quick and safe inspections; adjustments; service; operation; and maintenance, which includes de-energizing and grounding the equipment under emergency conditions (e.g., rescue of injured personnel). Articles 110-16, 110-17, and 110-31 through 110-34 of the NEC provide space requirements for specific applications.
- Enclosures shall be designed in full compliance with the examination, identification, and installation requirements specified in Article 110-13 of the NEC.
- Enclosures must be made of materials strong enough to contain hazards as electrical systems with sufficient energy can accelerate projectiles or start a fire. Similarly, capacitors with stored energy of as little as 225 J are capable of exploding and causing significant damage.
- Circuits having an energy greater than 10 J and operating levels above 50 V shall be identified with an appropriate label. The live contact points of these circuits shall have a caution sign, barrier, or guard.
- Manual grounding devices for high-energy equipment shall be fully visible and in compliance with ANSI standards or the manufacturer’s requirements for personnel and equipment safety. Grounding points shall be clearly identified and color coded in accordance with the requirements in the NEC.

Grounding and bonding of all noncurrent-carrying metal parts of the enclosure and its contents shall continually provide a path for leakage current to ground, eliminating the effective dielectric capacitance between the ground and metal enclosure.

Work Practices

- Warning signs shall be posted at the access points of enclosures indicating the nature of any hazards and precautions to be observed.
- Safety procedures shall be posted at the entry points of high-energy enclosures.

2.2.10 Control and Instrumentation Circuits

Design Practices

- When possible, control circuits should be designed such that the risk level will not increase without warning if one component fails. Indicator lights (pilot lights) on these circuits sometimes can be misleading because failure of a lamp might be interpreted as a de-energized circuit. For this reason, these circuits should have different color pilot lights to indicate when a circuit is energized or de-energized or a push-to-test provision.
- Control circuits shall not be placed in the same conduit, cable tray, or raceway as high-voltage circuits (>600 V). When used with high-voltage equipment, these circuits shall
  - — Have permanent and continuous ground.
  - — Be sized and rated to safely conduct the fault current likely to be imposed on them.
  - — Have sufficiently low impedance to limit the voltage to ground.
  - — Facilitate operation of their protective devices.
  - — Have one side fused and the other grounded. Where it is necessary to operate them ungrounded, both sides of the circuit may be fused.
- The disconnect switch for control circuits shall be installed with the handle in the down (or off) position.
- Disconnect switches and circuit breakers shall be legibly marked to indicate their purpose and position of operation.

Work Practice. Records shall be maintained of all equipment design and modification drawings and other documents.

2.2.11 Laser and RF Equipment

Laser Equipment. Troubleshooting or servicing of laser equipment exposes workers to significant electrical hazards, as specified in ANSI Z136.1 (Safe Use of Lasers). Thus, it is important to ensure that laser systems have the following design features (taken from ANSI Z136.1, Section 7.4, “Electrical Hazards”):

Design Practices

- Laser resonator and electro-optical elements should be designed so that no exposed metallic element is above ground.
- The frames, enclosures, and other accessible noncurrent-carrying metallic parts of laser equipment shall be grounded.
- Laser equipment shall be grounded by providing a reliable, continuous metallic connection between the parts to be grounded and the grounding conductor of the power wiring system.

RF Equipment. All RF electrical equipment shall be grounded in full compliance with Article 250 of the NEC and ANSI/IEEE 80 and ANSI/IEEE C2, except where experimental conditions indicate otherwise.

Work Practices. Only suitable barriers or insulated shields shall be provided when using this type of equipment. In addition, a safety procedure (OSP, FSP, or other document) shall be written covering the safe operation of the experiment.

2.3 Electrical Equipment/Wiring in Hazardous Locations

Article 500 of the NEC requires the use of specialized equipment and wiring in locations classified as hazardous (i.e., areas where flammable vapors, liquids, gases, or combustible dusts may be present in flammable or combustible concentrations during normal operations [i.e., spray painting in a booth] or from an accident or unplanned event). Personnel shall not work on energized equipment in these locations because of the hazards that may be present.

The NEC has defined three classes and two divisions of hazardous locations (NFPA 70 provides more details). Explosives handling areas may be Class I or II, depending upon the properties of explosives present. Chapter 24 of the *Health & Safety Manual* and Chapter II, Section 8, of the DOE *Explosives Safety Manual* provide specific guidance for explosives work. Hazards Control also can provide further guidance on whether planned operations or electrical wiring will fall into these categories.

2.4 Other Electrical Apparatus and Systems

Work on electrical systems not covered in this supplement must be performed in full compliance with the guidelines in Table A-1, Appendix A, or in accordance with current, documented, and approved safety procedures, work practices, or LLNL policy. Special procedures, responsibilities, limitations, and authorities shall be conspicuously posted.

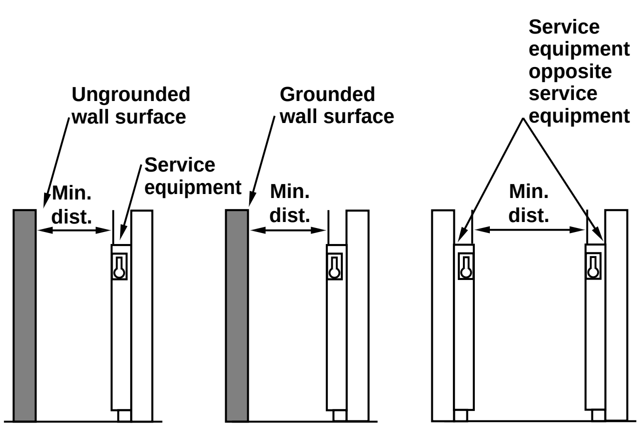
3.0 Clearances and Work Spaces for Electrical Equipment

3.1 Electrical Equipment Rated at 600 V or Less

The clearance and working space around electrical enclosures (panel boards, switches, circuit breakers, controllers, power supplies, heating and air conditioning controls) shall be adequate for all anticipated activities (e.g., maintenance, operation) and to ensure the safety of personnel during emergencies (e.g., rescue of injured personnel). In accordance with Section 110-16 of NFPA 70 (National Electric Code (NEC)), a 30-in-wide work space (either centered or offset in front of the equipment) is required as a minimum for electrical equipment rated at 600 V or less so that qualified employees working on the equipment can avoid contact with metal or grounded parts. The depth of the work space shall be clear from the floor to the required height, depending on the conditions described below and as specified in Fig. 1.

- **Condition 1** means that electrical equipment is mounted or set on one wall and the wall on the opposite side is insulated (ungrounded parts). The clearance specified in Fig. 1 for this condition allows a qualified worker making contact with the insulated wall to be isolated from the ground.
- **Condition 2** means that electrical equipment is mounted or set on one wall and the wall on the opposite side is grounded. The minimum clearance specified for this condition is required to prevent a fatal shock in the event a qualified worker accidentally makes contact with the conductive wall while touching live components.
- **Condition 3** means that electrical equipment is mounted or set on one wall and additional electrical equipment is mounted or set on the opposite side of the room. The minimum clearance specified for this condition is required because there may be live components on both sides of the room and a qualified worker might accidentally make contact with these components and be in series with a hot phase and the grounded metal of the electrical equipment. This could result in a fatal shock.

There also shall be at least a 90° opening in the work area for doors or hinged panels of equipment being serviced. Working spaces may overlap.



Condition 1		Condition 2		Condition 3	
Volts to ground	Min. dist.	Volts to ground	Min. dist.	Volts to ground	Min. dist.
0 - 150 V	3 ft.	0 - 150 V	3 ft.	0 - 150 V	3 ft.
151 - 600 V	3 ft.	151 - 600 V	3 1/2 ft.	151 - 600 V	4 ft.

Figure 1. Clearances for electrical equipment rated at 600 V or less. NOTE: A minimum clearance of 2-1/2 ft (for Condition 1) is allowed for installations completed before April 16, 1981.

3.2 Electrical Equipment Rated above 600 V

Figure 2 shows minimum clearances and work spaces for high-voltage electrical equipment such as switchboards, control panels, switches, circuit breakers, and motor controllers. Section 110-34(a) and Table 110-34(a) of the NEC also provide a list of clearances for devices.

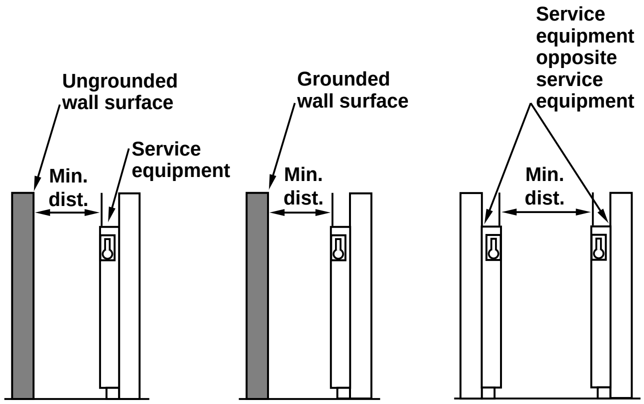
Minimum work clearances are required for electrical equipment with more than 600 V when (1) exposed live components are on one side of a space and ungrounded parts are on the other; (2) exposed live components are on one side and grounded parts are on the other (e.g., concrete, brick, and tile walls that are grounded); and (3) exposed live components are on both sides. Section 110-16(a) and Table 110-16(a) of the NEC provide additional information on clearances for this type of equipment.

4.0 High Potential Insulation Testing

High-potential testing of equipment is typically called "Hi-Pot." Hi-Pot tests are used during the design, manufacture, installation, and maintenance of equipment or for fault location testing. In any test, the manufacturer's instructions and procedures shall be followed exactly. At LLNL, Hi-Pot testing shall be performed only on de-energized equipment or during installations. Test units built at LLNL shall have the following built-in safety features:

- Grounded metal enclosures and insulated panels.
- Safety interlocks to shut off the high voltage, if the high-voltage range switch is turned on or the system is accessed during any portion of a test.
- Shielded plug-in outlet cables.
- Limited current output.
- An output bleeder that discharges dielectric charge from both the Hi-Pot equipment and test item.
- Adjustable electronic circuit breakers in the metered-return circuit that trip at any set current leakage between 10–5000 μA.
- Secondary circuit breakers that turn off the high voltage when the output exceeds 5 mA.

To avoid an effective capacitance shock after high-potential insulation testing, a ground shall be connected solidly to drain off or discharge dielectric charge on the insulation for a period equal to four times the testing limits.



Condition 1		Condition 2		Condition 3	
Volts to ground	Min. dist.	Volts to ground	Min. dist.	Volts to ground	Min. dist.
601 - 2,500 V	3 ft.	601 - 2,500 V	4 ft.	601 - 2,500 V	5 ft.
2,501 - 9,000 V	4 ft.	2,501 - 9,000 V	5 ft.	2,501 - 9,000 V	6 ft.
9,001 - 25,000 V	5 ft.	9,001 - 25,000 V	6 ft.	9,001 - 25,000 V	9 ft.
25,001 - 75,000 V	6 ft.	25,001 - 75,000 V	8 ft.	25,001 - 75,000 V	10 ft.
above 75,000 V	8 ft.	above 75,000 V	10 ft.	above 75,000 V	12 ft.

Figure 2. Clearances for electrical equipment rated above 600 V.

5.0 Responsibilities

5.1 Employees

Individuals shall only perform electrical work for which they are qualified and authorized. They also shall

- Understand the basic principles of electricity and electrical safety and the safe work practices delineated in this supplement.
- Follow the regulations, standards, and requirements set forth by the Occupational Safety and Health Administration (OSHA), NEC, DOE, and LLNL.
- Use the proper tools and PPE.
- Request additional training to prevent working beyond their level of qualification.

5.2 Supervisors

Individuals responsible for directing the work activities of others shall ensure that these workers

- Comply with the requirements in the *Health & Safety Manual* and, as guided by the ES&H Team, comply with requirements set forth by OSHA, NEC and DOE.

- Follow the safe work practices delineated in this supplement.
- Have (and use) the proper PPE.
- Are qualified and authorized to perform the work assigned.

5.3 Hazards Control Department

Hazards Control is responsible for providing guidance on planned operations and hazards analyses of electrical equipment and systems.

5.4 Electrical Safety Advisory Board

The Electrical Safety Advisory Board (ESAB) was established on February 20 1996 to support all LLNL facilities with electrical safety issues. This includes, but is not limited to recommending safe work practices for electrical equipment; developing, reviewing, and approving electrical safety training programs; and evaluating electrical accidents to determine the root cause(s). Detailed information on the board's full responsibilities can be found in Chapter 23 of the *Health & Safety Manual*.

6.0 Additional Information

6.1 Training

Basic and supplementary training requirements for LLNL electrical workers are described in Chapter 23 of the Manual.

6.2 LLNL Contacts

For further information on the topics discussed in this supplement, contact the following:

- Technical Support and Policy Development Division (TSPD), Hazards Control (ext. 3-5026).
- Machine Tool Services Group (ext. 2-7518).
- Plant Engineering Electric Utilities Division (ext. 2-9517).
- Plant Engineering Electric Main Shop (ext. 3-7758).
- ES&H Team (ext. 2-8253).

6.3 Sources for Additional Information

6.3.1 Referenced Standards

American National Standards Institute and the Institute of Electrical and Electronic Engineers:

"National Electrical Safety Code," ANSI/IEEE C2 (latest edition).

"Shunt Power Capacitors," ANSI/IEEE 18.

"Guide for Safety in AC Substation Grounding," ANSI/IEEE 80.

American National Standards Institute and the National Electric Manufacturers Association, "Enclosures for Electrical Equipment (2000 V maximum)," ANSI/NEMA 250.

American National Standards Institute and Underwriters Laboratories, "Light Industrial Tools," ANSI/UL 16724.

Institute of Electrical and Electronic Engineers:

"Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries for Generating Stations and Substations," IEEE 450.

"Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations," IEEE 484.

National Fire Protection Agency:

"National Electric Code," NFPA 70.

"Inspection Frequency," NFPA 70B.

"Electrical Safety Requirements for Employee Workplaces," NFPA 70E.

"Electrical Standard for Industrial Machinery," NFPA 79.

"Stored Energy Systems," NFPA 110A.

Occupational Safety and Health Administration, 29 CFR 1910, "Industry," and 29 CFR 1926, "Construction."

6.3.2 Other Standards

Federal Information Processing Standards 94, FIPS-94.

National Fire Protection Agency:

"Flammable and Combustible Liquids Code," NFPA 30.

"Standard on Fire Protection for Laboratories Using Chemicals," NFPA 45.

"Hazardous Chemical Data," NFPA 49.

"Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids," NFPA 325M.

"Manual of Hazardous Chemical Reactions," NFPA 491M.

"Recommended Practice for Classification of Class l Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas," NFPA 497A.

"Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations," NFPA 497M. [Contains a more complete list of flammable liquids, gases, and solids.]

Plant Engineering Department, "Panel Board and Circuit Numbering Standard," PEL-E-16196.

Underwriters Laboratories, Inc., *Hazardous Location Equipment*. [Contains a directory of listings and classifications.]

U.S. Department of Energy, *Electrical Safety Guidelines*, DOE / ID-10600 (May 1993).

U.S. Department of Energy, *Explosives Safety Manual*, DOE M 440.1-1 (latest edition).

Appendix A

Guidelines for Working on Energized Equipment

This appendix contains guidance for work on energized electrical systems and equipment. Additional guidance can be found in this supplement and in Chapter 6 of the *Health & Safety Manual*. NOTE: **This guidance is not a substitute for proper supervision of persons working with hazardous electrical systems or equipment. Furthermore, it is incumbent upon both qualified workers and their supervisors to carefully plan any work to be carried out on energized systems.**

A.1 Competent Person/Safety Watch

An individual may work alone on any system verified to be de-energized and properly locked out and tagged. However, if the equipment is energized and is a Class 2 or higher, another competent person (or safety watch) must be present until the work is complete.

A competent person is qualified and authorized by management to take prompt corrective measures to eliminate hazards (e.g., turn off equipment), provide first aid, and notify the appropriate personnel when an accident or incident occurs. This individual therefore shall

- Be capable of identifying existing or predictable hazards.
- Understand the hazard class associated with the equipment and the procedures for de-energizing equipment in an emergency.
- Know who to contact for assistance.
- Be qualified to perform cardiopulmonary resuscitation (CPR).

In the capacity of safety watch, this individual is specifically assigned to stand by within audible and visible range of workers and continually monitor the equipment and personnel for safety.

A.2 Special Precautions

It may be necessary to work on an energized system during troubleshooting if additional hazards may be created by de-energizing the system or if it is not possible to work on it de-energized because of its design. In such cases, workers shall

- Not wear conductive articles such as watches, rings, and other jewelry while working in close proximity of electrical circuits.
- Consider all electrical equipment and conductors to be energized until otherwise verified by a qualified and authorized person.
- Wear the appropriate PPE while performing the work. Additional details on PPE can be found in Chapters 10 and 23 of the *Health & Safety Manual.*

Additionally, workers and their supervisors shall consider the following factors for special or unique situations:

- Are environmental issues of concern (e.g., wet or damp locations or hazardous or explosive atmospheres)?

- Are accurate schematics available?
- Do workers have experience working with the type of equipment or situation involved?

A.3 Work Practices for Energized Systems

Apply the work practices in Table A-1 to energized electrical systems and equipment.

A.4 Work Practices for Batteries

Apply the following work practices to battery systems (electrolytic cells, batteries, and uninterruptible power systems):

- For equipment with <50 V and a short-circuit current of <10 A, apply the work practice in Table A-1 for Class 1 equipment hazards. This work practice also applies to typical dry-cell batteries used in flashlights and radios.
- For equipment with <50 V and a short-circuit current ≥10 A, apply the work practice in Table A-1 for Class 2 equipment hazards.
- For equipment with ≥50 V, apply the work practices for the appropriate equipment hazard class specified in Table A-1.

Table A-1. Work practices for energized systems based on their hazard class. The hazard class is based on potential contact with exposed, energized parts operating at the levels specified. All system voltages are measured as RMS or DC values; pulsed systems require further analysis. Where the operating level may be in more than one hazard class, the work practices for the highest hazard class shall apply. NOTES: A three-phase power source is a one-branch circuit, which counts as one source. A split-phase power source with a common neutral circuit (Edison circuit) counts as two sources.

Equipment/system hazard class	Work practice
Class 1: Includes systems with branch circuit voltage <140 V, branch circuit current limited to 30 A, and exposed voltage <50 V. If the source is limited to <5 mA, the exposed voltage may be >50V.. The stored energy for these systems is <10 J.	One qualified person may work alone on the equipment with general supervision.
Class 2: Includes relatively simple systems with exposed voltage <245 V and stored energy <10 J. Workers must fully understand all hazards associated with these systems.	One qualified person may work alone on the equipment with general supervision, but another competent person shall be positioned within visible and audible range of the worker.
Class 3: Includes systems with exposed voltage ≥245V and stored energy ≥10 J. These systems shall have no more than two exposed energy sources ≥50V. Workers must fully understand all hazards associated with these systems.	The project engineer or supervisor shall assign two qualified persons to perform the work. These individuals must work within audible and visible range of each other. An OSP or management-approved written procedure, specifically addressing the electrical hazards and controls, is required.
Class 4: Includes any system or equipment that is not described in one of the previous categories. These systems are complex because they have energized, exposed parts and large, dispersed arrangements of components, and may not be well understood.	Two qualified persons and a safety watch are required to perform the work. An OSP, specifically addressing the electrical hazards and controls, is required. If the OSP is not signed by a Division Leader or higher level of management, then the worker must get written approval prior to beginning the work.